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ITS PRODUCTION

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PREFACE.

IN presenting this monograph to the public, I make no claim for its completeness, nor of my infallibility, but take pleasure in giving the reader some facts concerning mechanical draft in a handy form for ready reference.

Some of the material has already appeared in an article which I prepared for the *Engineering Magazine.*

Credit for the work of others is given as far as possible.

I trust that the book may be read as being unbiased, as far as any particular make of apparatus is concerned.

The rapid sale of the first edition of this book has led to its reissue as one of the *Van Nostrand's Science Series*, with a few corrections and additional matter added.

WILLIAM WALLACE CHRISTIE.

Paterson, N. J., Nov. 1901.

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FURNACE DRAFT.

Its Production by Mechanical Methods.

A CHIMNEY is a means most frequently employed to provide draft for the combustion of fuel under or in boilers or other heat devices.

It provides the draft by means of the waste heat, or a waste of heat; the draft being a result of the difference in weight of a column of comparatively cold air without, and a column of comparatively very hot air within the chimney; the writer would call draft produced in this way natural or static draft.

Draft produced by mechanical methods as in the case of a blower, or steam jet, could be termed forced or dynamic draft. It is dynamic or forced draft with which we are directly concerned at present.

The particular method of producing draft to which the term "forced draft" is or has been applied, is that which employs a centrifugal fan which forces air in a closed ashpit, up through the bed of fuel, the gases passing out of a short chimney. This method is not used for excessively heavy fires, nor in large boiler units; it being necessary to shut off the fan before firing fresh coal, as the air forces itself through the fire in spots, unless closely watched, giving a very unsatisfactory combustion.

Forced draft has the advantage of being easily installed, and that no specially cooled bearings are needed on the fan as it handles cool air.

Forced draft is regulated in part by means of a valve or hood connection to the inlet pipe located in the ashpit of the boiler, having a rod extending to the outside of the setting which may be used to open or close a flap valve as conditions require.

Induced draft is a system much less generally used than "Forced Draft;" the fan drawing the air through the fire and boiler to itself, the result is more nearly like natural draft from a chimney, and it has no serious effect on the fire, nor does it interfere in the least with charging fresh coal while the fan continues to run.

The high temperature of the escaping gases, however, necessitates a design of fan suited to the purpose. Especial attention must be paid to the design of the journal boxes of the fan; these are usually kept cool with a water jacket, a device which has proven all that is needed for the purpose.

While fans for forced draft may be made of cast iron, fans for induced draft are always made of sheet steel. In either instance peripheral discharge fans are used, high pressure not being as much needed as a great volume of air at a moderate pressure.

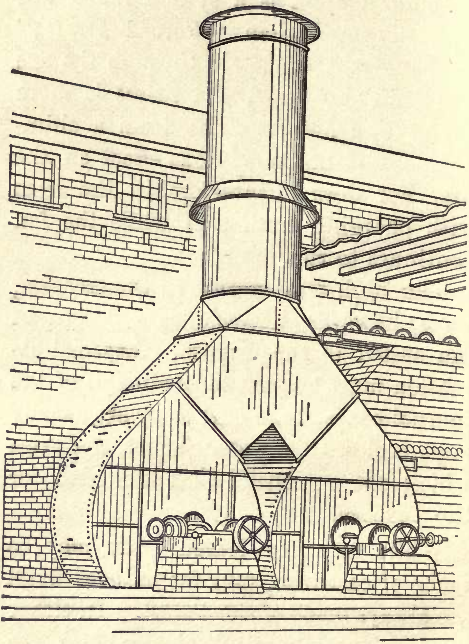
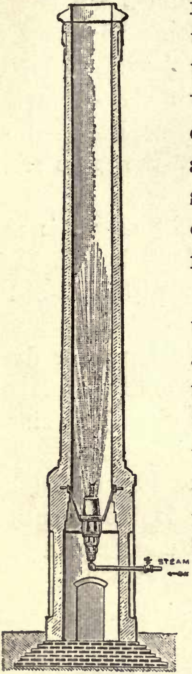


Fig. 1.
Induced Draft Plant.

A chimney which extends at least 10 feet above the roof of the building containing the fan or fans is used with either method in order to prevent fire, and to carry the gases so high as not to be offensive to the community.

Frequently for architectural effect, or on account of local regulations, the chimney is made higher; and again where looks are of no consequence the chimney may be omitted altogether.

Another system that is often employed is Forced-Induced draft, a combination of the two systems mentioned above.



Blast Nozzle Suspended in Brick Chimney.

Eynon-Evans Co.

Fig. 2

Still another system is Forced-Natural draft in which a centrifugal fan is employed to furnish the air necessary to combustion, also to regulate the same to suit the steam pressure carried in the boiler; a chimney being used to produce the draft and exhaust the gases from the furnaces.

An absolutely air-tight ashpit is not needed with this method, but is both desirable and necessary with "forced" draft.

A steam jet in the chimney or flue, is frequently used to create draft or assist and increase that already obtained by the heat of the escaping gases.

The large quantity of steam used by the [jets in proportion to the quantity made in the boiler plant using steam jets will be considered later.

In connection with a chimney to assist in exhausting the gases, a steam blower (not jet) is occasionally used, being placed in the furnace front or side wall of a boiler setting having a closed ashpit.

As is the case with the jet, the blower is a large consumer of steam. The advantages of mechanical draft as compared with natural-chimney-draft are well summed up by Mr. Jas. Howden, of England, as follows:

1. Complete combustion of fuel of all qualities under conditions in which combustion could not be efficiently obtained by natural draft.

2. The power of regulating with ease the amount of combustion desired, from zero to many times that possible by natural draft, also the capability of maintaining the fuel in the furnace incandescent for a considerable time without appreciable consumption.

3. A great reduction in the size or number of boilers required to produce a given power, and the capability of increasing the power in steamships far beyond that now obtainable with boilers worked by natural draft.

4. Greater economy in producing steam from the following causes:

(*a*) From more complete combustion of fuel than is attainable by natural draft with a reduced admission of air.

(*b*) From the higher temperature of the furnace arising the more perfect and higher rate of combustion, and from the air supply being partially heated before entering the furnace.

(*c*) From the utilization of the waste heat of the escaping gases.

(*d*) From the prevention of heat from the furnaces and ashpits being radiated into the stokehold.

(*e*) From the much less expenditure required to supply the air of combustion from a fan than is required to heat a column of air in a chimney, to obtain supply by natural draft.

(*f*) From preventing a cooling down of the boiler by a rush of cool air to the furnace, when a furnace door is opened.

5. Less discomfort in stoking, the stokehold fresh and cool by the radiation of heat from the furnaces being pre-

vented, and the fan drawing fresh air into it continuously independently of ventilators.

6. The complete absence of the great nuisance of smoke in the use of steam power.

7. The abolition of all unsightly chimneys in town and country now necessary for combustion by natural draft.

The readiness with which one of these systems may be adapted to any of the various conditions that exist is a point in its favor.

The convenience of the outfits leads to their adoption, in many cases; for on short notice—a few days or even less—a forced draft outfit may be ordered, received and installed. Likewise we can as readily arrange for a steel chimney of reasonable diameter and height.

Forced draft and chimney draft may be regulated within the extreme limits provided by, or inherent to the outfits themselves.

The economy in burning cheap fuels is an inducement offered to steam users in favor of forced draft; the cheaper grades of fuel may also be burned in a properly designed boiler furnace using natural draft.

A draft required for the efficient combustion of all fuels, in the majority of cases, is within the limit of that produced by a chimney of moderate height, which can be seen from the accompanying tables.

Draft Required for Efficient Combustion of Fuels.*

	Inches of Water.
Straw	0.20
Wood	0.30
Sawdust	0.35
Peat, light	0.40
Peat, heavy	0.50
Sawdust mixed with small coal	0.60
Slack, ordinary	0.6 to 0.9
Steam coal, round	0.4 to 0.7
Slack, very small	0.7 to 1.1
Coal dust	0.8 to 1.1
Semi-anthracite coal	0.9 to 1.2
Breeze and slack mixed	1.0 to 1.3
Anthracite, round	1.2 to 1.4
Breeze and coal dust mixed	1.2 to 1.5
Anthracite slack	1.3 to 1.8

* Dr. R. H. Thurston.

This Table Compiled by the Author from Actual Tests.

Coal per sq. ft. of grate per hour. lbs.	Draft in inches of water.
Rice Coal.	
14.8	0.88
17.9	0.54
21.3	1.10
21.5	1.01
25.8	0.89
27.0	1.04
28.	0.92
28.	1.26
Buckwheat Coal.	
16.4	0.54
16.7	0.59
19.8	0.34
19.8	0.37
20.14	0.58
22.3	0.87
22 3	0.93
26.1	0.96
26.3	1.23
27.3	0.94
30.2	1.10
31.4	1.00
32 5	1.08
32.9	0 83
33.7	0.80
45 4	1.68
Relative rates of Combustion.	
Pea Coal	100
Buckwheat.	85
Rice...	70

Coal per sq. ft. of grate per hour. lbs.	Draft in inches of water.	Temp. of escaping gases deg. F.	Height of chimney. Feet.	
Slack.				
18.4	0.41	365	133	
23.9	0.51	368	133	
33 2	1.16	538	192	
Run of Mine Bit. coal.			H. P. devel.	% Ashes.
6 49	0.16	371		8.33
*6 49	0.15	351	52	8.72
8.89	0.21	414	75	6.04
*9.33	0.28	361		7.42
12.13	0.33	444	100	6.15
*12.30	0.31	412	105	5.55
*15.80	0.38	424	125	5.81
16.35	0.36	470	150	4.93
*17 45	0.39	436	150	5.06
19 20	0.42	455		4.93
*19.73	0.53	447	170	5 76
20.87	0.51	506	170	4.96
*23.86	0.71	490		5.49
26.55	0.65	526	200	4.63
*27.32	0.86	523	225	4.53
30.10	0.62	551		4.43
34.30	0.67	646	240	4.25
Anthracite Tests by E. B. Coxe—Max. Sizes.				
13.63	0.375	Oneida Pea $\frac{7}{8}$ in.		
13.58	0.5	No. 1 Buck 9-16 in.		
11.40	0.625	No. 2 " $\frac{3}{8}$ in.		
11.33	1.04	No. 3 " $\frac{3}{8}$ in.		
9.44	1.125	Eckley 3-16 in.		

* Tubes having retarders, Hor. Tub. Boiler Tests.—*Trans. A S. M. E.*, Vol. 17.

INITIAL HEAT.

According to Kerl, the initial or free heat, or temperature to be reached to allow the particles of carbon to properly ignite with those of oxygen, is as follows:

SUBSTANCE	DEGREES	
	C.	Fahr.
Peat	225	437
Pine	295	563
Soft Coal	326	619
Charcoal made by low heat	360	680
Charcoal made by high heat	600–800	1112–1472

HEAT OF COMBUSTION.

1 lb. C to CO_2 gives 8140 calories, or 14,650 B. T. U.

1 lb. C to CO gives 2474 calories, or 4450 B. T. U.

1 lb. C from CO to CO_2 gives 5666 calories, or 10,200 B. T. U.

1 lb. CH_4 to CO_2 plus H_2O gives 13,305 calories, or 23,950 B. T. U.

[N. E. C. M. A., No. 58.—E. B. Coxe.

The results in evaporation of water when using different grades of small anthracite coal has been determined by a large number of tests,* giving us the following averages:

	lbs. water from and at 212° F.	
	per lb. coal	per lb. combustible
Buckwheat............	8.77	11.07
Rice (No. 2 Buckwheat).	9.05	11.18
Culm (pea, buckw., rice, barley and dust)......	8.74	11.19
Barley (No. 3 Buckwheat)	8.39	10.89

Not from same mine.

In a general way we may say there is no difference in evaporative results when using any of the above coals.

The rate of combustion with forced draft may be increased far beyond 25 lbs. of coal per square foot of grate per hour, which is about all that is desirable to have with chimney draft, to as much as 120 lbs. and even more, as in locomotive practice, for in the Purdue Tests we have a rate of 240.8 lbs. reported, and this without a very great loss in efficiency, as we shall see later.

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* N. E. C. Mfrs. Assn. No. 58—Coxe.

One of the large installations of Induced Draft is in the Electric Power House, 59th Street and East River [Power, Dec. 1897] where 2 or 3 14-ft. fans draw the gases through American Fuel Economizers, and then to further reduce their temperature and remove the soot, etc., the gases are passed about baffle plates, much as steam is sent through a separator, and then in a scrubber from which they emerge at about 100 deg. F.

This plant has a short steel chimney just sufficient to clear the roof of the buildings in the immediate vicinity.

The space occupied by centrifugal fans is often that above the boiler setting, and as such is considered of no particular value; in a like manner steel chimneys are frequently set on boiler settings and do not take up as much space in a horizontal plane as a centrifugal fan.

In the installation of the steam plant of the Lacombe Electric Co., Denver (Fig. 3), not only is the forced draft apparatus occupying room away from the boilers, but is of necessity under cover of a steel truss roof. Steel chimneys when located out of doors take up much less space than in this lay-out, and while brick chimneys may take up as much room, still they eliminate the roof expense, and the exterior dimensions of the base of the foundation is about the same in brick and self-supporting steel chimneys.

Large brick, or any brick chimneys cannot be moved intact as readily as can steel ones, or centrifugal fans, and the portability of the fan is a point that has been raised in its favor.

If a company is in business only for a few months, almost any draft device will do, but should they intend to continue in business for a longer period, portability will not cut much of a figure in any system of draft production.

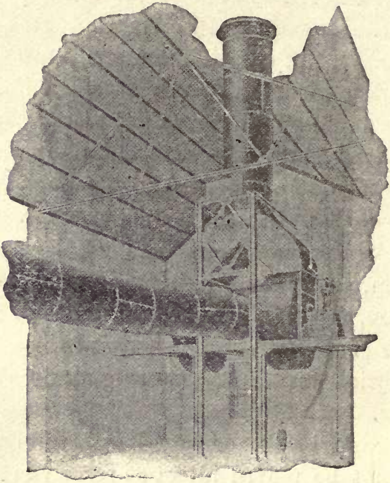

Fig. 3.

Induced-Draft Plant.

Lacambe Electric Co., Denver, Col

If the rate of combustion is increased by mechanical methods, so that we obtain sufficient evaporation from a part of the plant, we can dispense with one or more of the boilers; the increased rate of combustion, however, which must be attained to do this, will naturally give us a less efficient rate of evaporation of water per pound of coal, so that the user will need to decide which is the more desirable, to get the most out of the coal for its cost, or the most out of the plant for its first cost only. With an increased rate of combustion, we have added wear and tear on all parts of the boiler; this expense is also to be considered.

As nearly all well conducted boiler plants have an extra boiler or two, so as to allow of one or more being out of commission all of the time for cleaning or repairs, there is no advantage in having a "smaller boiler plant."

DAVIDSON'S SYSTEM.

A system of forced draft invented by Mr. Davidson of Belfast [Elec. Times—London] consists of a cylindrical box of diameter equal to the furnace fitted on its front, from which cast-iron tubes project at a slight declivity over the fire, through which air is blown over or into the fire, and by tubes into the ashpit, the air in it is also kept under pressure.

Tests made on four boilers thus equipped, at a large manufacturing plant showed

	A.	B.
Coal used during working hours..................	50 tons	64½ tons
Gallons of water evaporated during working hours...	80000	80000
Evap. per lb. of coal......	7.14 lbs.	5.53 lbs
Cost of coal per week, £.s.d.	23.19.2	17.14.9

or a saving of 25% in coal bill by using forced draft, B, over natural draft, A. (*St. Eng.*, v. 3, p. 250).

The late Eckley B. Coxe, probably more than any other man, understood the successful burning of small anthracite coal.

In a paper* before the New England Cotton Manufacturers' Association in

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* N. E. Cotton Mfrs. Assn., No. 33, p. 142.

1895 on this general subject, when treating of steam-making and boiler settings, he gives the unavoidable losses of combustion as follows:

"*First.*—The heat lost by converting into steam the water contained in the coal, in the air used in burning it, and that formed by the burning of the hydrogen and heating it to the temperature at which the gases leave the stack.

"*Second.*—The heat necessary to raise the carbonic acid gas formed by burning the carbon, the nitrogen present in the air, and the sulphurous anhydride, that may be formed by burning the sulphur, to the stack temperature. When we have perfect combustion there will also be a certain amount of free oxygen in the stack gas, which must also be heated to the same temperature, as it is impossible not to have a certain excess of air when the combustion of the coal is complete or nearly so. There is also a certain amount of heat lost by heating the ashes which are taken from the ashpit at a

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temperature above that at which the coal enters the furnace, and there is a certain amount of unconsumed carbon remaining in the ash which occasions a loss, in many cases a large one. The latter can, by careful firing, be very much reduced, but can never be entirely eliminated. There is also an unavoidable loss occasioned by the radiation from the boilers and walls, which, by careful construction, and coating the plant as far as possible with non-conducting materials, may be reduced, but never eliminated.

"The avoidable or partly avoidable losses are:

"*First.*—Those due to incomplete combustion. Too large a proportion of the carbon may be unconsumed and pass out with the ash, a portion of the carbon instead of being burnt to carbonic acid may be converted only into carbonic oxide, and thus 69.62 per cent. of the heat units in the carbon be lost, a certain amount of hydrogen and marsh gas may be allowed to pass out of the stack, and all the heat units contained in them be lost.

"*Second.*—Loss from excess of air. While theoretically, to burn one pound of carbon it is necessary to use only 11.60 pounds of dry air, yet in practice this is not possible, as every particle of oxygen in the air cannot be brought in intimate contact with the incandescent fuel at the proper time, so that it is necessary to use more than the theoretical quantity. But in most cases the excess is far beyond what would really be required if the firing is carefully done.

"This occasions great loss.

"*First.*—Because all the oxygen not used and the nitrogen which accompanies it must be heated to the stack temperature, and heat thus lost; and

Second.—Because it is practically impossible to obtain air free from moisture, which must be converted into steam and heated to the stack temperature. As vapor of water carried into the fire by the air causes a loss, it is evident that the artificial introduction of moisture, either by wetting the coal or by producing the blast with steam must necessarily increase materially the loss of heat in the stack gases.

"*Third.*—The next avoidable cause of loss is too high a stack temperature. It is self-evident that the heating of the vast amount of stack gases which are between ten and thirty times the weight of the coal burned, above the temperature to which they can be economically reduced, is a very serious waste, particularly if this temperature is very much in excess of what it should be.

"*Fourth.*—Loss by removing the ashes at too high a temperature. In many cases the ashes are so hot when taken from the furnace that they have to be wetted down. Of course all this loss of heat that can be avoided, represents so many dollars thrown away.

"*Fifth.*—Loss by radiation. It is important to have the outside surface of the plant, up to the point at which the gases cease to give up their heat, as small and as cool as possible, either by increasing the thickness of the walls, or by covering everything exposed to the air as much as conveniently can be done with non-conducting material, as the radiation increases with the area exposed, and with the difference in temperature of the surface of the walls above that of the surrounding atmosphere."

We shall now consider the first three of the avoidable losses:

(*a*) The loss from incomplete combustion is due largely to poor firing and careless cleaning of fires, when much unburnt fuel passes through the grates, or when with too strong a draft the particles of coal dust are blown to the chimney or exhausted to the blower before they are consumed.

(*b*) The loss from excess of air is one to which we cannot give too much thought.

One pound of carbon requires 11.6 lbs. of air for its complete combustion.

Though there is much uncertainty as

to just how much air is used in the burning of fuel, it is said that with forced draft 50 per cent. excess air is required in addition to the theoretical quantity, or a total of 18 lbs. of air per pound of coal.

When natural chimney draft is used 100 per cent. excess of air or 24 lbs. of air per pound of coal.

First Case.—Natural draft, 60 deg. F. temp. of outside air. Escaping gases, 60 deg. plus 440 deg., or 500 deg. F.

One lb. of coal requires, with 100 per cent. excess of air, 24 lbs. of air.

Second Case.—Forced draft, 60 deg. F. temp. of outer air. Escaping gases, 60 deg. plus 240 deg., or 300 deg. F.

To raise one lb. air—First case requires $0.2377 \times 440 = 105$ B. T. U.

To raise one lb. air—Second case requires $0.2377 \times 240 = 57$ B. T. U.

One lb. of coal, forced draft, wastes 18 lbs. of air, with 57 B. T. U. each lost, or 1126 B. T. U. per lb. coal. One lb. of coal, natural draft, wastes 24 lbs. of air, with 105 B. T. U. each lost, or 2520 B. T. U. per lb. of coal.

Under the above noted conditions there is a waste of 2520—1126 or 1394 B. T. U. per lb. of coal burned with natural draft as compared with forced draft. Considering the heat units per lb. of coal as 14200 B. T. U. we have a heat loss from using natural draft equivalent to

$$\frac{2520 \times 100}{14200} = 17.74 \text{ per cent.}$$

We have a heat loss from using forced draft equivalent to

$$\frac{1126 \times 100}{14200} = 7.93 \text{ per cent.}$$

From the above we have a heat loss of 17.74—7.93=9.81 per cent. from using chimney draft, which may seem to be in favor of forced draft by a centrifugal blower, but it can readily be appreciated that when the air needed to complete combustion, or admitted to the fire when natural draft is used, approaches the quantity sent through the fire by a blower, there is less and less economy of the blower over the chimney until when the amount of air is the same, no difference exists as to the economy of the one method over the other, excepting the interest and operating expenses of the blower, which latter is a considerable item and one not to be lightly turned aside. The influence of surplus air and a common temperature of escaping gases on the economy of a boiler is shown by what E. B. Coxe says: "If you have 3 per cent. free oxygen, 17 per cent. carbonic-acid gas, and 80 per cent. nitrogen, and a stack temperature of 500 deg. F., the heat loss is 12.27 per cent.

If you have 1 per cent. of carbonic oxide, 3 per cent. of free oxygen and 16 per cent. of carbonic acid, and a stack temperature of 500 deg. F., the heat loss is 16.12 per cent.

Thorough burning of (CO) carbonic oxide is necessary to a high heat efficiency.

From the following table:

Air at 300 deg. F. has a volume of 1.546 cu. ft.
" 500 " " " 1.954 "
based on a volume of 1 for air at 32 deg. F.

So that from the above the chimney moves about 26.39 per cent. greater volume of air than the fan.

Composition of Dry Air.

	By Weight	By Volume
Nitrogen.......	76.815	79.04
Oxygen	23.185	20.96
N/O...........	3.313	3.7709

[From J. P. Cooke's *Principles of Chemical Philosophy.*]

Table of Weight and Volume of Dry Air.

Atmospheres	Pressure		Volume in Cubic Feet
	Pounds per Sq. In. above a Vacuum	Pounds per Sq. In. above the Atmosphere (Gauge Pressure)	
1.00	14.70	0.00	1.0000
1.10	16.17	1.47	0.9346
1.25	18.37	3.67	0.8536
1.50	22.05	7.35	0.7501
1.75	25.81	11.11	0.6724
2.00	29.40	14.70	0.6117
2.50	36.70	22.00	0.5221
3.00	44.10	29.40	0.4588
3.50	51.40	36.70	0.4113
4.00	58.80	44.10	0.3741
5.00	73.50	58.80	0.3194
6.00	88.20	73.50	0.2806
7.00	102.90	88.20	0.2516
8.00	117.16	102.90	0.2288
9.00	132.30	117.60	0.2105
10.00	147.00	132.30	0.1953
15.00	220.50	205.80	0.1465
20.00	294.00	279.30	0.1195
25.00	367.50	352.80	0.1020

Volume and Weight of Dry Air

at Different Temperatures under a constant Atmospheric Pressure of 29.92 inches of Mercury in the Barometer (One Atmosphere), the Volume at 32 Degrees Fahrenheit being 1.

Temperature in degrees	Volume in cubic feet	Weight of a cubic foot in pounds	Temperature in degrees	Volume in cubic feet	Weight of a cubic foot in pounds
32	1.000	0.0807	650	2.260	0.0357
42	1.020	0.0791	700	2.362	0.0338
52	1.041	0.0776	750	2.464	0.0328
62	1.061	0.0761	800	2.566	0.0315
72	1.082	0.0747	850	2.668	0.0303
82	1.102	0.0733	900	2.770	0.0292
92	1.122	0.0720	950	2.872	0.0281
102	1.143	0.0707	1,000	2.974	0.0268
112	1.163	0.0694	1,100	3.177	0.0254
122	1.184	0.0682	1,200	3.381	0.0239
132	1.204	0.0671	1,300	3.585	0.0225
142	1.224	0.0660	1,400	3.789	0.0213
152	1.245	0.0649	1,500	3.993	0.0202
162	1.265	0.0638	1,600	4.197	0.0192
172	1.285	0.0628	1,700	4.401	0.0183
182	1.306	0.0618	1,800	4.605	0.0175
192	1.326	0.0609	1,900	4.809	0.0168
202	1.347	0.0600	2,000	5.012	0.0161
212	1.367	0.0591	2,100	5.216	0.0155
230	1.404	0.0575	2,200	5.420	0.0149
250	1.444	0.0559	2,300	5.624	0.0142
275	1.495	0.0540	2,400	5.828	0.0138
300	1.546	0.0522	2,500	6.032	0.0133
325	1.597	0.0506	2,600	6.236	0.0130
350	1.648	0.0490	2,700	6.440	0.0125
375	1.689	0.0477	2,800	6.644	0.0121
400	1.750	0.0461	2,900	6.847	0.0118
450	1.852	0.0436	3,000	7.051	0.0114
500	1.954	0.0413	3,100	7.255	0.0111
550	2.056	0.0384	3,200	7.459	0.0108
600	2.158	0.0376			

[From *Compressed Air*.]

Calorific Power and Air Required per Cubic Foot.

1 Cubic Foot	B. T. U. at 60° F. and 30″	Cubic feet required		Cu. ft. formed of	
		O.	Air	Steam	CO_2
Hydrogen........	326.2	.5	2.39	1	0
Carbon Monoxide	323.5	.5	2.39	0	1
Marsh Gas	1009.0	2.0	9.56	2	1
Olefiant Gas......	1558.0	3.0	14.34	2	2

Air = 20.92 per cent. of Oxygen.
1 lb. Carbon burning to CO_2 requires 11.6 lbs. of air.
1 lb. Carbon burning to CO requires 5.8 lbs. of air.
[R. D. Wood & Co.]

From tests made at the Electro-technical Exhibition, Frankfort-on-Main, in 1891, we have for two types of water-tube boilers these results:

Per ct. heat utilized by boiler....	70.00	73.30
" " lost in escaping gases	17.70	17.70
" " " ashpit........	1.70	3.10
" " unaccountable, radiation, etc..........	10.60	5.90
Total loss	100.	100.
Times theoretical quantity of air supplied	2.00	1.82
Temp. escaping gases, degrees F.	545.9	590.
Water gauge (with Siegert Durr's Instrument)...............	0.43 in	0.20 in

[See *N. E. C. M. A.* No. 58, p. 168, for more complete table]

The heat lost, etc., confirm in a general way the previous calculations.

The losses from too high a temperature of the escaping gases are common to boiler plants, and with a blower forcing the draft, the temperature may easily and frequently does become excessively high.

The economy of the low flue temperatures, combined with comparatively low rates of combustion, low percentages of CO, and little or no free oxygen in the escaping gases, is shown quite conclusively by the following reports of actual tests:

Tests of a Babcock and Wilcox Boiler.*

APRIL, 1899. Day…….	11th	12th	13th	14th
Average per cent. CO_2………	10.7	10.9	10.9	11.1
" " O……….	7.8	7.7	8.1	8.7
" " CO …….	.5	.02	.06	0
Ashpit…………………….	clos'd	open	clos'd	clos'd
Air Supply…. ………….	cold	norm.	hot	cold
Temperature escaping gases, uptake deg. F…………	619	445	572.7	521
Temp. outs. air, deg. F…….	55.1	52.4	64.9	62.
" fire room, deg. F……..	71.0	66.3	96.1	83.75
" of air entering ashpit….	……	……	165.5	
Vacuum in chimney….inches	1.43	0.43	1.41	.61
Rate of combustion…….coal	46.39	19.88	41.88	28.82
Equiv. evap. from and at 212° F. per lb. comb., atmos.pres.	10.18	11.79	11.21	12.15

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* For U. S. S. Alert, 1899.— *St. Eng. Rep.*, U. S. N.

Niclausse Boiler.*

May, 1899. Day......	2d	3d	4th	5th	6th
Average per cent. CO_2...	6.18	5.07	4.95	6.74	7.10
" " O......	11.58	13.73	13.63	11.62	9.60
" " CO ...	.94	.62	.77	.53	.90
" " N.....	81.30	80.58	80.65	81.11	82.40
Temp. esc. gases, deg. F.	......	525	464	389	794
" outside air, "	84.6	70.7	62.	69.4	69.
" fire room, deg. F...	98.2	80.4	79.8	85.	96.6
" of air entering ash-pit, deg. F..........	106.4	189.1	......	......	319.9
Rate of combustion, coal.	26.63	26.79	23.87	14.24	46.18
Equiv. evap. from and at 212° F. per lb. combus.	10.24	10.38	9.76	10.78	9.22

Gas Analysis—Boiler Tests.

		Rate of Combustion.	Equiv. evap. per lb. Combus.	Per Cent.			Pounds Dry Gas per lb. Carbon.	Temp. escaping Gases.
				CO_2	O	CO		
	1	20.45	12.19	14.0	4.5	1.1	16.8	466 deg.F.
	2 H.	20.95	12.70	12.7	5.7	0.0	19.1	493
	3 H.	34.06	11.47	13.1	4.2	1.5	17.3	608.6
	4 H.	35.61	11.50	12.8	5.7	0.6	18.8	570.6
Blower and Steam Jets both in use	5	50.95	11.43	11.8	6.9	0.4	20.6	640.0
	6 H.	48.31	11.12	14.5	4.8	0.2	17.7	637.0
	7	59.75	10.52					less than 900 deg.F.

Pocahontas—Flat Top Mine—Coal was used in all tests. Contained considerable slate; clinkered badly.

[*St. Eng. Rep.*,U. S. N., 1900. See same for full details.]

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* For U. S. S. Alert, 1899.—*St. Eng. Rep.*, U. S. N.

From tests of boilers* where forced natural draft was used, these results accompany very economic evaporation:

Boiler pressure, by gauge, lbs. per sq. in.........	63	68	70	71
Temp. escaping gases deg. F.	346	355	395	400

Another avoidable furnace loss is too high temperature of the escaping gases; for example, in tests made on B. & W. boilers with Coxe Stokers, at Deringer, Pa., we have:

Rate of Combustion, lbs........	9.8	20.34
Temp. of escaping gases, deg. F.	449.5	900
Equiv. evap. per lb. of combustion, lbs....................	11.28	8.51
Air pressure in ashpit, inch. water	0.60	1.00

The loss in evaporation in the second test accompanies a very high temperature of 900 deg. F.

A forced draft plant now in operation, without an economizer, delivers the escaping gases at such a high temperature, say 1,000 deg. F., that at times they heat the short steel chimney to a dull-red heat.

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* Barrus.

In the Otto Colliery, Branchdale, Pa., cylinder boilers under forced draft deliver the gases at about 1,600 deg. F., and vertical boilers, 711–732 deg. F., in both of which the evaporative efficiency is low.

The highest evaporative efficiency of a gun-boat type of horizontal boiler was reached with the temperature of escaping gases at 516 deg. F., with a certain type of vertical boiler 500 deg. F., another 421 deg. F.

Forced draft used alone generally results in higher temperature of the escaping gases than is usual with natural chimney draft; we here have another objection to forced draft.

The Purdue tests show that after a certain high rate of combustion has been reached, as it increases the temperature of the escaping gases decreases—the same total quantity of coal being burned in a given time on a grate of varying area, under the same boiler, but that point is reached only at a very large rate of combustion.

Coal per hour per square foot of grate.................lbs.	61.40	83.50	124.20	240.80
Temp. of escap. gases..deg. F.	647	629	610	500
Draft, in inches of water......	2.20	2.50	3.30	5.60
Equivalent evaporation per lb. of combustion...........lbs.	8.26	7.87	7.59	6.67

Noting for example that the temperature of steam under 100 lbs. pressure by gauge is 338 deg. F., and 150 lbs., 366 deg. F., we can readily see that the nearer the temperature of the escaping gases is to the temperature of the steam in the boiler the more economical the boiler is, the temperature of the flue gases should not exceed 400 deg. to 500 deg. F. for economy.

The utilization of the heat of waste gases, or the waste heat in escaping gases, especially when forced draft is installed, is best accomplished in many cases by putting in an Economizer as an adjunct to the boiler plant.

It is to all intents and purposes a feed water heater, and is described by one manufacturer as follows:

The Economizer consists of a series of sets of cast-iron tubes about 4 inches in diameter and 9 feet in length, made in sections (of various widths) and connected by "top" and "bottom headers," these again being coupled by "top" and "bottom branch pipes" running lengthwise, one at the top and the other at the bottom, on opposite sides and outside the brick chamber which encloses the apparatus. The waste gases are led to the Economizer by the ordinary flue from the boilers to the chimney.

The feed water is forced into the Economizer by the boiler pump or injector, at the lower branch pipe nearest the point of exit of gases, and emerge from the Economizer at the upper branch pipe nearest the point where the gases enter.

Each tube is provided with a geared scraper, which travels continuously up and down the tubes at a slow rate of speed, the object being to keep the external surface clean and free from soot, a non-conductor of heat.

The mechanism for working the scrapers is placed on the top of the Economizer, outside the chamber, and the motive power is supplied either by a belt from some convenient shaft or small independent engine or motor. The power required for operating the gearing, however, is very small.

The apparatus is fitted with blow-off and safety valves, and a space is provided at the bottom of the chamber for the collection of the soot, which is removed by the scrapers.

Economizers are not installed in America so extensively as in Europe, for the European design of boiler costs less per H. P. than the American boiler and consequently Americans put in more boiler and less Economizer.

In America, where boilers are comparatively expensive, the Economizer is used to take the gases after they leave the boiler, and reduce them, by heating feed water to the lowest possible temperature.

Economizers in no way alter the conditions in the boilers of plants of which they form a part, but they materially, in many—yes, in most of cases, add to the efficiency of the steam plant.

From four tests made by Mr. Barrus, we have:

	1	2	3	4
Degrees of temp. of gases lost in Economizer.............	145	107	104	156
Degrees of temp. of feed water raised in Economizer........	80	66	58	92
Degrees of temp. of gases leaving Economizer.............	231	254	299	279
Per cent. increase in evaporation due to Economizer.....	10.5	7	9.3	12.8

The evaporative efficiency of the boiler being increased from 7 to 12.8 per cent.

In these tests the temperatures of the gases leaving the Economizer were from 231° to 299° F.

Had the gases not passed to an Economizer, the temperature of 500° F., or 961.2° absolute, would be compared with 231° or 691.2° F. absolute or with 299° F.

or 760.2 absolute, in order to ascertain the intensity of chimney draft produced in either case, and as the intensity is a direct function of absolute temperatures, we can say in a general way that the loss of intensity of draft due to the loss of heat in the economizer is 30 per cent.; therefore, to produce the same draft in an economizer plant, a chimney say 41 per cent. higher than for an ordinary installation without an economizer would be necessary. It is because of the gases reaching the chimney of a given plant at a temperature below 300 deg. F. that forced combustion is employed to provide sufficient draft without using a chimney for the purpose. Unless the boilers and economizers are designed with special reference to forced combustion, the gases are likely to escape from the boiler setting at a much higher temperature than with natural draft, resulting in an inefficient boiler; at the same time the gases leaving an economizer in a forced draft plant are frequently not so very much lower than may be obtained with natural draft.

Whatever saving there may be in a blower-economizer outfit over natural chimney draft should be credited to the economizer alone.

With a chimney alone producing draft we have a heat loss of about 17.74 per cent. (50 excess air.) With a blower alone, a heat loss of 8 per cent. to which we should add the cost of operating the blower which is from 1 to 7 per cent. of the steam made in the boilers.

Anthracite Pea Coal.	Averages lbs.
5 tests—Stationary Tupper grates—Natural draft................	10.17
4 tests—Shaking grates—Natural draft	10.45
3 tests—Shaking grates—Natural draft and Steam Blower (steam made used in blower).........	10.39
Anthracite Buckwheat Coal.	
1 test—Shaking grates—Natural draft	10.86
2 tests—Shaking grates—Natural draft and Steam Blower (steam made used in blower)	9.96

With a blower and economizer outfit

which gives the same flue temperature as in a chimney and economizer, we have a loss which is the cost of operating the blowers.

Two Vertical "Manning" Boilers, when operated under the conditions named, gave the preceding equivalent evaporation from and at 212 deg. per lb. of combustible, showing as far as they go the economy of shaking grates.

All of the blower methods of draft production must be considered in connection with, and be planned with especial regard to the quantity of fuel to be burned in a given time, and the amount of air needed for the complete combustion of the fuel, which air must necessarily pass through the blowers.

18 to 25 lbs. of coal per square foot of grate per hour is all the coal that should or can be burned with economy under natural draft, a greater amount necessitates forced draft.

Another thing which should not be lost sight of in connection with the burning of small coals, is that the unburnt coal falling through the grate which in the case of anthracite culm has reached 58 per cent. (found in the ashes).

Fan, Stoker and Economizer Engines in a 24-hour test used 800 lbs. of coal to burn 19,612 lbs. of coal or 4.01 per cent. Sturtevant Fan, American Stoker and Green Economizer.—*Eng. Rec.* Vol. 42, p. 348.

The effect of the temperature of the gases on the power required to operate a fan, is shown clearly by the following:

Effect of Temperature of Gases on Fan Load.

Induced Draft.	1	2	3
Draft in inches of water..............	0.42	0.46	0.24
Temperature of gases at fan, deg. F..	199.6	162.5	330
Speed of fan, revolutions per minute..	154	179	230
Current req. by fan motor, amperes..	10.3	13.3	20.4
Current generated by plant, amperes..	896	1236	960
Proportion used by fan, per cent.....	1.15	1.17	2.08
Boiler H. P. developed	521.7	600.6	439.2

The blower used was an American Blower Co.'s centrifugal fan with 28 × 84 inch wheel.

FANS FOR INDUCED DRAFT.

Induced Draft Capacity Table for Steel Plate Fans.

Temperature gases, 550 degrees F.; Barometer, 29.92; 34.5 ℔s. water per H P.; Temperature air. 62 degrees F.; 18 ℔s. air per 1 ℔ coal.; Evaporation, 6.9 ℔s. water per 1 ℔. coal; Draft pressure. 1 inch W. G.; 5 ℔s. coal per H. P. hour; CO_2 =90 per cent. weight coal.

Size of Fan.	Diam. Wheel inches.	Width at Periphery.	Diam. of Inlet.	Size of Outlet. Inches square.	Speed R. P. M. for 1-inch Draft.	Capacity of Fan in cubic feet per minute, Temp. Gases 550 deg. F.	H. P. Boiler Capacity from Fan Capacity.	Pounds Coal per hour at 5 pounds per H. P. hour.	Evaporation per hour at 34 5 pounds Water per H. P.	Brake H. P. to drive Fan at Speed.	Capacity of Fan per inch Width at Periphery.	H. P. per inch Width at Periphery.	Cubic feet Air per minute for Combustion, Temp. 62 deg. F.
50	30	12½	20	18	740	5,030	116	580	4,000	2.02	403	.162	2.260
60	36	14¼	23.	21½	615	6,900	159	795	5.500	2.76	485	.194	3,100
70	42	16½	26	24½	530	9,325	215	1,075	7.425	3.72	563	.226	4.200
80	48	17½	30	27	460	11,300	261	1,305	9.000	4.50	645	.258	5,100
90	54	20¾	34	30½	410	15,100	349	1,745	12,050	6.03	728	.290	6,800
100	60	23¼	38	34½	370	18,750	433	2,165	14.950	7.50	844	.322	8,450
110	66	26	42	37½	335	23,000	532	2,660	18,300	9.20	885	.354	10,370
120	72	30¼	46	41½	310	29,250	677	3.385	23,350	11.72	970	.387	13,200
140	84	34⅜	53	48	265	38,800	896	4,480	30,900	15.50	1,132	.452	17,450
160	96	38	60	54	230	49,000	1.130	5,650	39,000	19.60	1,290	.516	22,000
180	108	41¼	68	60	205	59,900	1,385	6,925	47,800	24.00	1,453	.581	27,000
200	120	47	76	66	185	75,500	1,746	8,730	60.250	30.25	1,610	.644	34,000
220	132	50	84	72	170	88,600	2,050	10,250	70,750	35.50	1,775	.710	40,000
240	144	54	92	78	155	104,600	2,420	12.100	83,500	41.80	1,940	.775	47,000

(American Blower Co.)

The third test, gases 130 deg. hotter than first, require about 100 per cent. more power, and yet the boiler evaporation is about 20 per cent. less than in the first test.—Curtis Pub. Co., by Davis & Griggs.

The cost of the above Mechanical Draft outfit (2 fans), including motors, was $5.53 per boiler H. P.

The data concerning Induced Draft Fans in the accompanying table is taken from the 1901 catalogue of the American Blower Co.

One of the recent installations of Induced Draft apparatus is that of the Curtis Publishing Co., Philadelphia, Pa., which contains 3 (250 H. P.) B. & W. Boilers for 160 lbs. pressure.

An old chimney 30 × 40 inches by 90 feet high.

The Induced Draft plant was installed in duplicate, i. e. one plant in reserve, by American Blower Co.

Fan, 120 inches, water cooled bearings, 8 H. P. Electric Motor.

Temperature of escaping gases 540 deg. F. from boiler.

Temperature of escaping gases 260 deg. F. from economizer.

The fan requires 1.4 of the power used by the plant.—(*Eng. Rec.* Vol. 43, p. 172.)

The economizer consists of two brick chambers, each containing 24-6 tube sections of $4\frac{9}{16}$ inch pipe, each pipe $7\frac{1}{2}$ feet long; cost, including masonry, was $5.73 per boiler H. P.

Results from Tests.

	4	2	3
	deg. F.	deg. F.	deg. F.
Temp. of gases leaving boilers . .	411	422	474
" " " " economizer	199.6	162.5	Ec'n. off
" " water entering "	116.9	38.2	" "
" " " " boilers . .	212.5	192.9	38.3
Saving due to economizer . per ct.	9.92	16.01	

[Davis & Griggs.]

ECONOMIZER TESTS.

Tests made at the 74th Street station of the Manhattan Elevated Railway, New York City, resulted in these facts:

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The unit of absorption is 3.5 B. T. U. per square foot per hour per degree difference in temperature.

Loss of draft in economizer

$$= \left(\frac{H}{3700}\right)^2 \times \frac{n}{64} \times 0.23$$

H = pounds of gases per square foot of draft area per hour.
n = number of sections in length of economizer.

During this test these averages were obtained as follows:

Water entering economizer.... 93.5° F.
Water leaving economizer.....203.8°
Temperature gases at chimney.399°
Draft entering economizer....0.64″
Draft leaving economizer......0.87″
Draft in chimney at base......1.16″
Chimney   feet high.

The Sturtevant Co. in "Mechanical Draft" give the following rule for capacity area of a blast fan:

The square inches of blast, or capacity area of a cased fan, is approximately:

$$\text{Capacity area} = \frac{D\,W}{X}$$

D = diameter of fan wheel in inches.
W = width of fan wheel at circumference in inches.
X = constant dependent on type of fan and casing.

In general practice X = 3.

The area of the casing outlet is always larger than the above figures give for capacity area.

The volume of air passing through the fan is calculated from the capacity area.

The power required to operate a fan varies with the air pressure, volume, temperature, and its efficiency in generation depends upon whether a belt-driven fan is used, or the power is furnished by direct connected motor or steam or other type of engine.

BLOWERS.

Sturtevant No. 2 monogram blower, no piping, 1800 revolutions per minute, 0.8 H. P. (D).

Sturtevant No. 9 foundry blower, supplying iron-melting cupola, 25 H. P. (W. 26).

No. 6 Sturtevant*—Fan wheel 23 in. diam. × $6\frac{5}{8}$ at periphery. Diameter of inlet on each side is $12\frac{1}{2}$ in.: 8 blades, area 45.59 sq. in. each. At a speed of 1468 rev. per min., blast 3 oz. to sq. in. took 3.55 H. P. with area of discharge of 44 sq. in. giving 2750 cu. ft. of air per min. At a speed of 1519 rev. per min. blast pressure, 3.5 oz. per sq. in.—0.8 H. P. with opening closed and no air delivered.

Mr. Snell ran air through a tubular heater placed about 30 feet from the blower; at 1100 revolutions per minute of blower, air was discharged at 161 deg. F., water would have been 190 deg. F.; at 2100 revolutions the air was a little higher temperature.—*Trans. A. S. M. E.*, Vol. 20, p. 89.

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* Topical Discussion, 222-226. *Trans. A. S. M. E.*, Vol. 7. Mr. H. I. Snell.

Steam to operate steam jet—7.4 of boiler evaporation.

Steam to operate steam jet—8.78 of of boiler evaporation.

Fan—4 per cent. of boiler evaporation used to drive the fan.

Fan—18 H. P. to supply 1800 to 1950 boiler H. P.

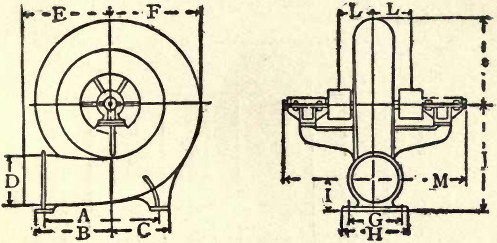
Fan—3.21 H. P. to supply 401.5 boiler H. P. (Whitham).

Fan—5.6 H. P. to supply 520 boiler H. P. (Wagner).

Admitted relative efficiency of fan to jet 8 to 1.

Buffalo Steel Pressure Blowers.

Table of Dimensions.



Size No.	A	B	C	D	E	F	G	H	I	J	K	L	M
1	7⅛	6	2¾	3½	7	5⅜	6⅜	8	2⅞	7	5½	3	14½
2	10	7⅝	4⅜	4	8½	6½	6¼	7¼	3⅜	9¼	6	4	19½
3	13	10	4⅞	4¾	11¼	8¼	7	8¼	3⅝	10¾	8½	4⅜	23
4	15	11⅝	5½	5	13⅛	10¼	9	11	4⅞	13½	10	5	25¼
5	15¾	12½	5¾	5⅜	14¼	12	11½	13½	5	14¼	11½	4⅝	24½
6	18¾	14	7½	6¼	15¾	13¼	13	15¼	6	16¾	13	5⅝	27¾
7	21¾	14½	10½	7¼	16¼	14¾	13½	15¾	7	19¼	14	6½	33¾
8	26½	17	12½	8¾	19	17	15	17½	8⅜	21½	16½	9	40
9	32	19½	16	10	22	20	16	19	9⅛	25	19	9⅜	41
10	40	23¾	20	12¼	28	25½	17½	20	10½	30½	25½	10½	45¼
11	43½	27½	25	14½	28	30½	21½	23½	11½	36½	29	12	50¾
11½	53	30	28	16½	33	36	23	27	12	41⅝	34	12⅜	53
12	53	30	28	18	33	36	23	27	12	41⅝	34	12⅜	53

Dimensions in inches.

Table of Speeds and Capacities in Cubic Feet per Minute.

(Forge.)

Number of Blower	4 Oz. Pressure			5 Oz. Pressure	
	Forges	R. P. M.	Cap.	R. P. M.	Cap.
2	3	4986	289	5596	326
3	5	3993	542	4473	607
4	6	3363	573	3754	642
5	7	2952	651	3308	730
6	8	2573	839	2883	940
7	11	2275	1002	2549	1123
8	16	2067	1501	2316	1681
9	22	1851	2136	2074	2393
10	32	1384	3116	1550	3491
11	40	1154	3845	1293	4308
11½	50	937	4741	1050	4734
12	60	937	5002	1050	5604

Number of Blower	6 Oz. Pressure		7 Oz. Pressure	
	R. P. M.	Cap.	R. P. M.	Cap.
2	6132	355	....	....
3	4910	666	5314	721
4	4121	705	4459	762
5	3631	801	3929	867
6	3165	1032	3425	1117
7	2798	1233	3029	1334
8	2543	1845	2750	1997
9	2275	2627	2460	2844
10	1702	3832	1842	4147
11	1419	4729	1586	5119
11½	1152	5831	1247	6312
12	1152	6152	1247	6658

Table of Speeds and Capacities for Cupola Service.

Number of Blower	Inside Diameter of Cupola	Pressure in Ounces	Revolutions per Minute	Melting Capacity in lbs. per Hr.	Cubic Ft. of AirRequir'd per Minute
4	20	8	4732	1545	666
5	25	8	4209	2321	773
6	30	8	3660	3093	951
7	35	8	3244	4218	1486
8	40	8	2948	5425	2199
9	45	10	2785	7818	3203
10	55	10	2195	11295	4938
11	65	12	1952	16955	7707
11½	72	12	1647	22607	10276
12	84	12	1625	25836	11744
4	20	9	5030	1647	717
5	25	10	4726	2600	867
6	30	10	4108	3671	1067
7	35	10	3642	4777	1668
8	40	10	3310	6082	2469
9	45	12	3260	8598	3523
10	55	12	2413	12378	5431
11	65	14	2116	18357	8358
11½	72	14	1797	25176	11144
12	84	14	1775	28019	12730

Cupola Practice Tests.

Root's Blower, Acme No. M.
Iron melted, 22 tons, 10 cwt. 5 tons melted per hour.

	Motor and Shaft light.	Blowing Cupola	
		Maxim.	Minim.
Revolutions	......	360	350
Volts	245	246	233
Amperes	14	104	66
E. H. P. Total	4.6	32.7	21.7
" Average	......	28.2	
Time, hours	......	4.5	

Root's Blowor. Acme No. K.
Iron melted, 12 tons. 7 tons melted per hour.

	Motor and Shaft light	Blowing Cupola	
		Maxim.	Minim.
Revolutions	......	430	394
Volts	232	237	225
Amperes	9.5	57.0	50.0
E. H. P. Total	2.96	17.1	15.2
" Average	......	15.94	
Time, hours	......	3.00	

The first cupola has a capacity of 7 tons per hour.

The American Blower Co. also gives this table of data concerning fans for forced draft, which only goes as far as fans with wheel 33 inches in diameter.

Blowers for Forced Draft.

Forced Draft Capacity Table for Blowers.

Temperature air, 62 degrees F.; 18 lbs. air per 1 lb. coal; 34.5 lbs. water per H. P.; Barometer. 29.92; 234 cubic ft. per 1 lb. coal; Evaporation, 6.9 lbs. Water per 1 lb. coal; Pressure, 1⅓ ounces; 5 lbs. coal per H. P. hour.

Size of Blower.	Diameter Wheel Inches.	Width at Periphery.	Diameter of Inlet.	Diameter of Outlet.	Speed R. P. M. for 1⅓ oz. Pressure.	Capacity Blower cu. ft. per min. Temp. 62 deg. F.	Lbs. Coal per hour 234 cu. ft. air per lb. Coal.	H. P. Boiler Capacity 5 lb. Coal per H. P. hr.	Evaporation per hr. 34.5 lbs. Water per H. P.	Brake H. P. to drive Blower at Speed.
1	8½	2	4⅜	4⅝	3300	348	90	18	620	.35
2	10¼	2¾	5⅛	5⅝	2650	512	131	26	896	.52
3	12	3¼	6⅛	6⅝	2320	711	182	36	1240	.73
4	15½	4⅜	8	8½	1800	1210	310	62	2140	1.24
5	19	5½	10	10½	1470	1830	468	93	3210	1.87
6	22½	6½	12	12½	1240	2600	666	133	4590	2,66
7	26	7½	14	14½	1075	3420	873	175	6030	3.50
8	29½	8½	15¾	16¼	950	4130	1055	211	7280	4.54
9	33	9½	17¾	18¼	845	5580	1425	285	9820	5.72

(American Blower Co.)

A Niclausse* (Marine Type) water tube boiler was under test on land, and it was desired to maintain a rate of combustion of 30 lbs. of coal per square foot of grate per hour. "It was difficult to regulate the blower so as to obtain the desired uniform rate of combustion." "The weather cleared and a fresh breeze sprang up, increasing in strength so that the blower, started at 500 revolutions, had to be gradually slowed to 330."

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* *St. Eng. Rep.*—U. S. N. 1899.

The maximum rate of combustion under this boiler with forced draft was 46.76 lbs. of coal per square foot of grate per hour, which may be considered the maximum for "naval vessels other than torpedo boats and destroyers."

One authority has carefully analyzed a representative boiler test, and gives the following losses: coal capable of evaporating 13.97 lbs. of water per lb., actually evaporated 9.68 lbs.:

Losses—	Chimney	12.59	per cent.
	Ashpit,	2.68	"
	Not specified	15.43	"
	Total	30.80	

The products of combustion are given by Williams as:

1. Steam—highly rarefied, invisible, and incombustible.
2. Carbonic acid—invisible and incombustible.
3. Carbonic oxide—invisible, but combustible.
4. Smoke—visible, partly incombustible, partly combustible. Hydrogen is invisible.

Carbon returns to black state and becomes visible. Much can be learned regarding the completeness of the combustion of fuel by the analysis of the escaping gases.

A large boiler with a good fire gave gases with:

16.5	per cent.	of CO_2
3.3	“	“ O
0.9	“	“ CO
71.3	“	“ N
92.0		

See Table X, pp. 158, 159, *Trans. N. E. C. M. A.* No. 58.

Smoke prevention is in reality complete combustion, and forced combustion aids or rather prevents smoke only in so far as it regulates the quantity of air fed to the fire.

One authority in Mechanics* some years ago gave these notes on smoke prevention:

" The question of smoke prevention has agitated the minds of engineers for many years, although pretty well solved by Mr. C. Wye Williams more than 20 years ago. Many of the so-called inventions of the present day are either mere copies of his or reinventions of what was known to him and used in his experiments. The principle of burning the gases of coal is best illustrated in the Argand and Siemen's burners for lamps, and depends wholly on a thorough and intimate mixture of air with the gas at a high enough temperature to insure combustion—i. e., the air must be mixed with the gas before the latter has been cooled down by contact with cold surfaces. Then by having openings for air through the doors, and by firing alternately and reversing the draft, the gas from the fresh coal is passed over the incandescent coal on the other side, and so burned before it reaches the combustion chamber or tubes, in which case the combustion chamber may be smaller than otherwise.

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* Published in Philadelphia, Pa.

"Another way is to have the fire chambers side by side, and supply the air at the bridge as the gases pass to the combustion chamber; then by firing alternately there is always a stream of hot gas coming in contact with the fresh gas from the fire chamber last fired, which insures a perfect combustion. In this case we have nearly the same conditions as in an Argand burner, burning ordinary illuminating gas. The fire chamber being the gas producer and the combustion chamber the burner, the combustion, commenced in the former, is completed in the latter, and the tubes absorb the heat, so that the carbonic acid passes away at a comparatively reduced temperature."

The effect of varying quantities of air can be readily seen by carefully studying notes of actual tests.

Rob. Kane, M.D., M.R.I.A., and R. H. Brett, Ph.D., F.L.S., conducted some elaborate tests on Williams's patent furnace, when they found that with ordinary charging of coal and usual air admitted much dense smoke passed through the flues at a temperature of 650 deg. F., admitting the proper quantity of air, finely divided—no smoke visible—temperature 1211 deg. F.; then shutting off one-half the air-inlets, giving one-half the amount of air as in the preceding test, lurid flame passed through the flues at 985 deg. F., and a light gray smoke issued from the chimney.

The following table by E. B. Coxe is abstracted from a quite extensive one published in the N. E. C. Manf. Assn. Trans. No. 58:

Table.

1 Gas analysis combustible in fuel burned 100 per cent. carbon.	2 Number of times the theoretical air supplied n.	3 Per cent. of heat lost when $T-t=500$ deg. F. Per cent. H.
$CO_2 = 21$ $N = 79$	1.00	10.1535
$CO_2 = 14$ $O = 7$ $N = 79$	1.50	14.8241
$CO_2 = 10$ $O = 11$ $N = 79$	2.10	20.4288
$CO_2 = 7$ $O = 14$ $N = 79$	3.00	28.8359
$CO_2 = 3$ $O = 18$ $N = 79$	7.00	66.2008

$$\text{Formula: } n = \frac{\frac{21}{79}N}{\frac{21}{79}N - On}$$

$$\text{Per cent. } H = \frac{[(11.5 \times n) + 1] \times .238 \times (T-t)}{14650}$$

TABLE.

Abstracted from same authority as the preceding table gives the number of times the theoretical quantity of air supplied, with various gas analyses:

1 $CO+CO_2$	2 $N=79$ CO_2+CO $+O=21$	3 $N=80$ CO_2+CO $+O=20$	
21	1.00		
19	1.10	1.05	Original table contains 5 columns, and Column 1 has every number from 21 to 1
17	1.23 5	1.16	
15	1.40	1.31	
14	1.50	1.39	
12	1.75	1.60	
10	2.10	1.89	
8	2.62	2.29	
7	3.00	2.57	
	4.20	3.39	
3	7.00	5.00	
	21.00	9.43	

Formula for values of columns 2 and 3 is

$$n = \frac{\frac{21}{79}N}{\frac{21}{79}N - On} = \frac{1}{1 - \frac{79\ On}{21\ N}}$$

These conditions can only exist when hydrogen is present in the fuel burnt, and has been converted into water.

GAS ANALYSES.

With a McClave grate and a steam jet blower the analysis was

CO_2 —8.20 per cent.
CO —13.15 “ “
H —11.08 “ “
CH_4 —2.00 “ “
O —0.30 “ “

With fan blower and stoker,

CO_2 —16.80 per cent.
O — 1.70 “ “
CO — .40 “ “

Mr. Magnus Troilius* in a paper on “The Analysis” of furnace gases gives for gas from producers:

CO_2	7.50	8.00
CO	16.00	15.50
H	15.30	14.90
CH_4	1.90	....

Which is very similar to the first above, showing by the large amount of (CO) carbonic oxide and (H) hydrogen that there is a decided loss of heat.

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* *A. I. M. E.*, 1883.

Blowers can be regulated; one would think that "damper regulators" had never been heard of in connection with chimneys; in fact, many plants are not now equipped with them.

The effect of the quantity of surplus air on the temperature of combustion in the furnace is for theoretical quantity of
air 4940° F. above 32° F.
50% additional air 3332° " " " "
100% additional air 2505° " " " "

When the gases are under pressure, as in stokeholds of vessels, the temperature of combustion is at ordinary atmospheric
pressure 2760° F. above 32° F.
at pres. of 2 atmos. 3475° " " " "
" " " 3 " 3968° " " " "

The first cost of steel chimneys for small horse-power is less than that of brick chimneys or forced combustion outfits.

For very large powers it costs less to install the blower systems, but though we have no operating expenses for chimneys we have the cost of the power used to operate the blower and economizer engine, if the latter is used.

We are told that compared with the cost of a good brick chimney

A forced draft plant costs 25 per cent. of the brick chimney;

A single induced draft plant costs 40 per cent. of the brick chimney;

A double induced draft plant costs 50 per cent. of the brick chimney: but that depends entirely upon the design of the chimney.

The life of a forced draft fan having constant use is said to be about fifteen years, while a well cared for steel chimney lasts from 20 to 25 years, if it is kept properly painted outside—the inside being protected with soot; a brick chimney lasts a hundred years.

The relative areas of grate surface to boiler heating surface, when forced combustion is used, should be decided by a careful consideration of the kind, quality, and quantity of the fuel to be burned.

"It has been claimed by the advocates of forced draft that more power is required to drive the fans* owing to their having to deal with heated gases; this we think we† can prove erroneous."

Experience has shown that in a properly designed installation it is not necessary to maintain an average vacuum of more than 2¼ inches water gauge at the fan inlet, the temperature of the gases to be dealt with being about 450 degrees F.

On the other hand, it is generally acknowledged that about three inches water gauge at the fan discharge is necessary to get the best results with forced draft, and as the air is taken from the engine room its temperature may be taken at 80 degrees F.

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* More for induced draft fans.

† Ellis and Eaves (Patent) System of Induced Draught.

If the supply of air to the furnace be[*] 12 lbs. per lb. fuel, then volume,

12 lbs. at 32° per lb. of fuel is 150 cu. ft.
18 lbs. do. do. do. 225 "
24 lbs. do. do. do. 300 "

The volume at any other temperature T is

$$V = \text{volume at } 32^\circ \times \frac{T + 461.2^\circ}{493.2^\circ} = V_0 \frac{r}{r_0}$$

The following are some of the results:

Deg. F. Temperature	Supply of air in lbs. per lb. of fuel. 12	18	24
	Vol. of gases per lb. of fuel in cu. ft.		
4640	1551		
3275	1136	1704	
2500	906	1359	1812
1832	697	1046	1395
1472	588	882	1176
1112	479	718	957
752	369	553	738
572	314	471	628
392	259	389	519
212	205	307	409
104	172	258	344
68	161	241	322
32	150	225	300

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[*] Rankine, *Steam Engine*, p. 286.

W = coal burned in a given furnace per second.

V_0 = Volume at 32° F. of the air supplied per lb. of fuel.

r_2 = Absolute temperature of the gas discharged by the chimney.

r_0 = Absolute temperature of the air at 32° = 493.2° F.

r = Absolute temperature at temperature T.

A = sectional area of the chimney; then the velocity of the current in the chimney in feet per second is

$$u = \frac{W V_0 r_1}{A r_0};$$

Density, lbs. per cubic foot = D

$$= \frac{r_0}{r_1} \left\{ 0.0807 + \frac{1}{V_0} \right\}$$

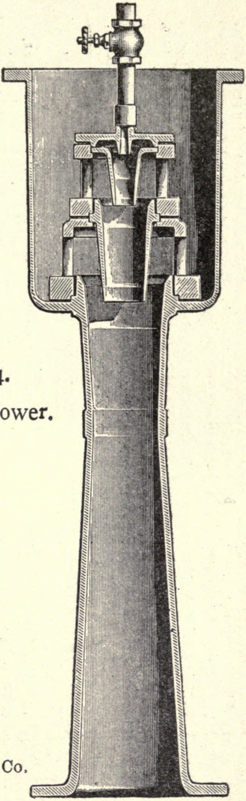

Fig. 4.
Steam Blower.

Eynon-Evans Co.

Comparative Test of Three Cylinder Boilers at Short Mountain Colliery, Lykens, Pa., 1896,

With STEAM AND FAN BLOWERS.

Fan Blower consisted of Gangway Fan 33 in. diameter. four paddles 9 in. x 9¼ in., driven by small slide-valve engine with cylinder 4 1-16 in. diameter. 7¾ in. stroke. Steam supplied by small upright boiler on which an evaporative test was run during the test on the cylinder boilers. Duration of test, 8 hours.

Steam Blower made of ¾ in. pipe, circle 6¾ in. diameter. 16 holes. tapered ⅛ in. outside, 1-16 in. inside diameter. Steam supplied by upright boiler on which test was run as above. Duration of test, 8 hours.

Dimensions of boilers 36 in. diameter 42 ft. long. Area grate surface, 3 boilers, 61.5 square feet.	With Steam Blower.	With Fan Blower.
COAL.		
Total coal burned (less moisture)	7,700 lbs.	6.100 lbs.
" ash	1.330 "	7.027 "
" combustible	6.370 "	5.073 "
Per cent. of ash	17.2 per cent.	16.8 per cent.
Coal burned per hour	962.5 lbs.	762.5 lbs.
Combustible burned per hour	796.3 "	634.1 "
WATER.		
Total water evaporated—actual conditions	39.241 lbs.	34.890 lbs.
" " " per hour—actual conditions.	4,905 "	4 361 "
Equivalent water evaporated per hour from and at 212 deg.	5,444 "	4,867 "
Water evaporated per hour per lb. of coal—actual conditions.	5 10 "	5.59 "
" " " " " " " combustible—actual conditions.	6.16 "	6.87 "
" " " " " " " coal from and at 212 deg.	5.66 "	6.38 "
" " " " " " " combustible from and at 212 deg.	6.84 "	7.67 "
H. P. developed per hour from and at 212 deg.	157.81 "	141.1 "
Average boiler pressure	77 "	78 "
Average temperature of feed-water	134 deg.	137 deg.

COMPARATIVE TEST—CONTINUED.

BLOWERS.		
Boiler H. P. used by blowers per hour from and at 212 deg..	11.9 H P.	5.64 H. P.
Per cent. of the developed H. P. of the three boilers used for blowers.	7.4 per cent.	4 per cent.
Cubic feet of air per minute.	2,502 ft.	3,506 ft.
Average water gauge..................	.44 in.	.52 in.
Horse-power in air..	173 H. P.	.28 H. P.
Steam used in blowers per ton fuel..................	830 lbs.	

REMARKS.

In test with fan blower the exhaust from fan engine was turned into air current, and found sufficient to keep the grates free from clinker.

Average steam pressure at steam blowers = 74 lbs.
" I. H. P. of fan engine, 1.62 H. P.
" number revolutions of fan engine, 160 rev.
" " " " " 915 "

Per cent.—Useful effect of fan. 17 per cent.

Trans. A. S. M. E., Vol. XX.—*Norris.* *Colliery Engineer*, August, 1897.

STEAM BLOWERS—DATA OF TESTS.*

1. Name of steam blower	McCLAVE. 18 4-64 in. Jet Holes, 1.2 in. Centres.							
2. Steam pressure at jets, lbs.	15	30	45	60	75	90	105	115
		plus	plus	plus	plus	plus	plus	plus
3. Ash-pit pressure, in. of water	0	.08	.10	.25	.33	.40	.42	.45
4. Vacuum in furnace, in of water	.06	.06	.08	.08	.08	.10	.08	.05
5. Total furnace draught, in. of water	.06	.14	.18	.33	.41	.50	.50	.50
6. Temp. of air fed to fires. deg. F.	56	56	56	56	56	56	56	56
7. Cu. ft. air injected per hour	187,700	128,100	157,200	178,560	202,020	228,000	264,120	276,968
8. Boiler H. P. used to operate blower.	....	9.42	10.66	11.00	12.38	15.32	....	....
9 Cu. ft. of air injected per hour per boiler H. P. expended to operate blower jets	....	13,600	14,747	16,233	16,318	14,882	....	....

TABLE OF DATA OF TESTS—CONTINUED.

1......	YOUNG. 20 5-64 in. Holes, 1⅜ in. Centres.						EYNON-KORTING. No. 5 Size ⅜ in. Orifice.							
2......	9.3	17.8	40	59.4	67.1	70.3	5	10	15	20	30	47½	60	75
	minus		plus	plus	plus	plus	minus	plus	plus	plus	plus	plus	plus	plus
3......	.10	0	.08	.15	.20	.25	.06	.01	.04	.09	.18	.45	.48	.76
4......	.35	.35	.33	.30	.30	.30	.23	.18	.19	.14	.14	.05	.06	.06
5......	.25	.35	.41	.45	.50	.55	.17	.19	.23	.23	.32	.50	.54	.82
6......	56	54	56	56	56	56	60	60	60	60	60	60	60	.60
7......	104,400	123,000	163,320	187,560	202,080	206,880	58,420	78,347	98,476	111,476	138,780	185,875	214,953	239,550
8......	6.31	9.44	12.91	16.87	20.06	....	3.50	4.78	5.45	6.40	8.10	10.90	13.30	15.90
9......	16,545	13,029	12,651	11,119	10,074	....	16,691	16,390	18,069	17,418	17,133	17,053	16,162	15,060

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*J. M. Whitham, Trans. A. S. M. E., Vol. XVII.

Summary of Steam Used to Operate the McClave and Young Steam Blowers.

Kind of coal (all from one mine).	Kind of boiler test.	Rated H. P. of boilers.	H. P. developed by boilers	Name of blower used.	No. of blowers used.	Boiler H. P. required to operate the blowers.	Per cent. of boiler H. P. required to operate blower jets.	Pounds of dry coal burned an hr. per sq. ft. of grate.	Per cent. of ash and refuse in dry coal.	Per cent. of air openings in grate bars.	Gauge steam pressure at the blower jets.	DRAUGHT IN IN. OF WATER.			
												Pressure in ash pit.	Vacuum in furnace.	Vacuum in stack flue.	Total draught.
Rice.	Capacity	250	378.2	Young.	2	42.0	11.1	25.8	28.4	11	70.3	0.59	0	0.30	0.89
"	Economy	250	270.0	"	2	18.9	7.0	17.9	26.4	11	17.8	0.24	0.10	0.30	0.54
B'kw't.	Capacity	250	374.2	"	2	40.1	10.8	27.3	29.1	11	67.1	0.61	0.08	0.33	0.94
"	Economy	250	272.2	"	2	12.6	4.6	16.7	28.7	11	9.3	0.16	0.18	0.31	0.49
"	Capacity	250	380.1	"	2	33.7	8.9	31.4	29.5	26	59.4	0.67	0.04	0.33	1.00
"	Economy	150	150.9	McClave.	1	10.2	6.7	16.4	25.6	11	37.4	0.32	0.11	0.22	0.54
"	Capacity	150	209.4	"	1	19.4	9.3	26.1	27.1	11	103.4	0.73	0.08	0.23	0.96

(Whitham).

Steam jets or steam blowers are means by which draft is assisted or created, but neither, as a rule, are employed without a chimney; while they are cheap in first cost and installation they are expensive to keep in repair and to operate.

Steam blowers under grates are frequently used in connection with mechanical stokers, also under boilers whose chimneys do not furnish the desired draft, and which boilers have become of insufficient capacity by the natural growth of a plant.

Steam jets are used in chimney flues for like reasons.

Two horizontal return tubular boilers tested by the writer:

A—boiler using steam blowers under the grates in connection with chimney draft,

B—chimney draft alone, resulted as follows:

	A	B
Boiler rated Horse Power.....	90	130
Boiler Horse Power Developed.	122.55	121.91
Equiv. Evap. from and at 212° per lb. of combustible......	10.76	10.73

(No. 2 anthracite pea coal used in both tests.)

One disadvantage in the use of steam jets or blowers is that just so much more water has to be heated in the chimney and carried up out of it; another and more serious objection is the large amount of carbonic oxide, hydrogen and marsh gas formed.

In one plant the writer found frequent explosions on the opening of the boiler furnace door, and the burning of the fireman's arms from explosions of marsh gas in the boiler; the explosions were seen to extend up into the main flue to the chimney.

Again, the steam required to run or operate the steam jets or blowers is large in proportion to the quantity of steam made under the boilers, having been given (*Trans. A. S. M. E.* Vol. XX) as from 7.4 to 8.78 per cent., and the relative efficiency of centrifugal fan blower to steam jet is as 8 to 1.

The capacities of the Steam-jet Blowers and Exhausters made by L. Schutte & Co., of Philadelphia, Pa., are:

Size No.	Quantity of air per hour in cubic feet	Diam. of pipe, inches	
		Steam	Air
000	1,000	½	1
00	2,000	¾	1½
0	4,000	1	2
1	6,000	1¼	2½
2	12,000	1½	3
3	18,000	2	3½
4	24,000	2	4
5	30,000	2½	5
6	36,000	2½	6
7	42,000	3	6
8	48,000	3	7
9	54,000	3½	7
10	60,000	3½	8

A greater rate of combustion can be obtained with the centrifugal blower than with a steam jet, and steam in the ashpit reduces the tendency of the coal on the grate to clinker and form an obstruction

Consumption of Steam Blasts Compared.*

Coal.	Name of blower.	Per cent. of air openings in grate.	Pounds of dry coal burned an hour per sq. ft. of grate.	Per cent. of total steam generated in the boilers that is required to operate the steam blasts
Rice.	Young.	11	25.8	11.1
"	"	11	17.9	7.0
"	Wilkinson.	7	27.0	10.8
Buckwheat.	Young.	11	27.3	10.8
"	"	11	16.7	4.6
"	"	26	31.4	8.9
"	McClave.	11	16.4	6.7
"	"	11	26.1	9.3
"	Wilkinson.	7	32.5	7.8
"	"	7	45.4	10.2

*Trans. A. S. M. E., Vol. XVII.—*Whitham.*

			**	Blower.	
Jet. No. 1.	Rate of combustion in boiler,	24.3	21.2	annular slit	
" " 2.	" " " "	35.2	20.7	33 1–32 holes	
" " 3.	" " " "	14.2	8.3	1-16 in. hole	Jet
" " 4.	" " " "	26.9	12.	⅛ in. "	
" " 5.	" " " "	27.7	14.	[illegible]-64 in. "	

**Per cent. of steam made required to operate jet or blower (U. S. Bureau of St. Eng., 1890.)

to the free passage of the air necessary to combustion.

It is the opinion of the writer that wherever it is at all practicable to do so, a chimney, or, what is much to be preferred, chimneys in multiple should be used; one of the largest contracting engineering firms who formerly were strong advocates of forced draft are now recommending chimney draft first for all plants with which they have to do.

It would seem that for the great majority of power steam plants, better returns (financially) would result from natural draft produced by means of, not any chimney, but by means of a chimney or chimneys designed especially for each plant.

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